Rock mass classification for rock slope stability assessment in Malaysia: a review

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Abstract. Rock mass classification systems are commonly used in the design and construction of rock engineering, and have seen widespread modifications and validations by various researchers over the last few decades. The rock mass classification, in particular the slope mass rating (SMR), continues to be the preferred preliminary method in small-scale assessment of rock slope stability. In Malaysia, parameters related to rock slope stability assessment have been modified to consider the condition of the rock mass such as the effect of heterogeneous rock units and weathering of rocks. The application of rock mass classifications however have been shown to contain some discrepancies, and the acknowledgement of the limitations of the system is important for an optimum use in the design stage. This paper reviews several development of rock mass classifications in Malaysia, as well as looking at potential direction of further development of the rock mass classification system in the context of local slope stability analysis.

1. Introduction

Development involving rock slope are usually related to highway construction, where large rock surface are excavated. Often times, these slopes are prone to instability problems, due to rock mass conditions and environmental external factors. Internally, factors such as the rock materials, slope height, slope face angle, and discontinuities affect the slope's stability. Over the years, various techniques and methods have been developed by researchers working with rock slopes, from the fields of tunnelling, mining, or conventional slope cutting. Malaysia have been subjected to several major landslides over the years, with several involving cut rock slopes on highway [1]. Geological condition have been reported to account only a portion of the contributing factor to landslide in Malaysia, accounting for a total of 8% [2]. However, due to the safety and economic factor involved in rock slope stability, the input of engineering geology to the process of excavation and treatment of cut slopes is still of great importance [3]. To mitigate potential slope failures in cut rock slopes, a proper understanding of the lithology and discontinuities in rock mass is thus necessary.

2. Assessment methods for rock slope stability

It has been noted by [4] that eight modelling methods for the purpose of rock engineering has been categorized, which includes pre-existing standard methods, analytical methods, basic and extended numerical methods, precedent type analysis, empirical classification, the basic system approach and the combined system approach. In this review the kinematic analysis and rock mass classification is discussed:

2.1. Kinematic analysis

Kinematic analysis represents one of the conventional methods of slope stability analysis, and is a purely geometric method which examines potential modes of failures in jointed rock mass through the usage of stereographic projection technique. The common method, originally proposed by [5], is later redefined by [6-7]. In the test, the great circle of the slope face and circle of friction angle, φ, is plotted on stereographic projection. The zone between the great circle and the friction circle (sliding envelope) represent the condition for failure, where the plunge value of the joint is less than the slope angle and greater than the friction angle of the joint. A review for case studies of engineering geology in Malaysia by [3] have cited the usage of kinematic analysis as the standard for local geologists and engineer geologists working on rock slopes. It could be observed that numerous local slope stability analyses employed kinematic analysis, either in conjunction or independent of rock mass classification systems. The method is however limited to the case of structurally controlled cut slopes, and have been noted to ignore the strength parameters of the discontinuities and of the rock mass, as well as acting forces on the slope the quantifiable slope stability condition is not given, as only the potential for slope failure is given [8]. Kinematic analysis still remains essential for evaluation of structurally controlled rock slopes, and has been recommended as the first step before proceeding to other analytical techniques of slope stability [9].

2.2. Rock mass classification

Rock mass classifications are one of the most widely known empirical classification for rock engineering. They represent the means for evaluating the performance of rock cut slopes based on important parameters, describing the rock mass condition quantitatively [10]. Due to their simplicity and reliability, the system enjoys wide usage among practitioners, having been time-tested for more than three decades [11]. Summary and discussion of existing rock mass classification systems can be found in the work of [10] and [12]. Rock Mass Rating (RMR) perhaps one of the most widely used empirical method for rock mass classification. Originally designed by [13] to evaluate the quality of rock mass while working in underground projects, the system contain five parameters representing different conditions of rock and discontinuities: strength of intact rock material (uniaxial compressive test or point load strength) (R_δ), rock quality designation (R_{RQD}), spacing between discontinuities (R_{SD}), condition of discontinuities (R_{CD}), and groundwater condition (R_{CG}) (1):

$$RMR = R_\delta + R_{RQD} + R_{SD} + R_{CD} + R_{CG} \quad (1)$$

The rock mass could be sorted into five classes: very good (RMR 100–81), good (80–61), fair (60–41), poor (40–21), and very poor (<20). The list of parameters and assigned value in the rating is given in table 1. From the classes, [15] provided guidelines for supports to tunnel excavated through conventional drilling and blasting. The Slope Mass Rating (SMR), devised by [16] modifies the RMR of [13]. The SMR system aims to remove ambiguities in RMR for the purpose of classifying rock slope. The SMR index adds four adjustment factors, with parameters that reflect joint-slope relationship (F1–F3), as well as method of excavation (F4) (2):

$$SMR = RMR + F1\ F2\ F3 + F4 \quad (2)$$

As with RMR, slope stability is divided five classes: completely stable (SMR 100–81), stable (80–61), partially stable (60–41), unstable (40–21), and completely unstable (20-0). SMR is one of the most widely used classification system used for the purpose of slope stability analysis, with subsequent modifications by workers further modifying the parameters from the system. [14] recommends the usage of [16] SMR for rock slope stability analysis.

Table 1. Rock rating system [14].

Parameter			Range of values				
1	Strength of intact	Point-load	>10	4–10	2–4	1–2	For the low range, uniaxial compression

	rock mineral	strength index (MPa)					test is preferred		
		UCS (MPa)	>250	100–250	50–100	25–50	5–25	1–5	<1
Rating			15	12	7	4	2	1	0
2	Drill core RQD (%)		90–100	75–90	50–75	25–50	<25		
Rating			20	17	13	8	3		
3	Spacing of discontinuities		>2 m	0.6–2 m	200-600 mm	60-200 mm	<60 mm		
Rating			20	15	10	8	5		
4	Condition of discontinuities		Very rough surfaces Not continuous No separation Unweathered wall rock	Slightly rough surfaces Separation <1 mm Slightly weathered walls	Slightly rough surfaces Separation <1 mm Highly weathered walls	Slickensided surfaces, or Gouge < 5 mm thick, or Separation 1–5 mm (Continuous)	Soft gouge >5 mm thick, or Separation > 5 mm (Continuous)		
Rating			30	25	20	10	0		
5	Ground-water	Inflow per 10 m tunnel length (L/min	None	<10	10–25	25–125	>125		
		Ratio of joint water pressure to major principal stress	0	<0.1	0.1–0.2	0.2–0.5	>0.5		
		General condition	Completely dry	Damp	Wet	Dripping	Flowing		
Rating			15	10	7	4	0		

Other notable rock mass classification systems include the Rock Tunneling Quality Index (Q) ([17], and the Geological Strength Index (GSI) [18-19]. The former is used for tunnel support work, while the latter deals with heterogenous and poor-quality rock mass.

3. Modification of rock mass classification

3.1. Modification in Malaysian context

As Malaysia is particularly vulnerable to landslides occurrence [1-2], several empirical methods for slope assessment and management have been developed over the years for in large-scale and medium-scale assessment of slope. [20] reviewed the accuracy of five slope assessment systems (SAS) developed by the Malaysian Public Work Department (PWD). The study found that none of the systems were satisfactory in predicting landslides in rock cut slopes, although one of the system (Slope Management and Risk Tracking System, SMART) seems satisfactory in predicting failures for metasedimentary rocks (table 2–3). The various reasons for the unsatisfactory prediction of landslide were cited to be the result of usage of hazard score developed from other country, insufficient database, the use of an oversimplified approach, and the use of database derived from a different rock/soil formation.

Table 2. Accuracy of the SAS in predicting landslides: granitic formation cut slopes [20].

Prediction	SMS	SPRS	SIMS	SMART	LHRA
(1) Number of slopes assessed	139	139	139	139	139
(2) Number of recent landslides or failed slopes	44	44	44	44	44
(3) Number of slopes classified as High and Very High Hazard that actually failed	17	23	1	27	1
(4) Percentage of (3) compared with (2)	39%	52%	2%	61%	2%

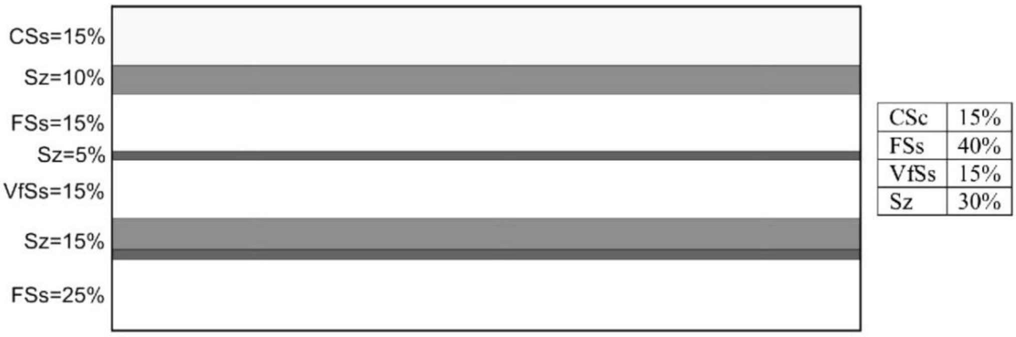
Table 3. Accuracy of the SAS in predicting landslides: meta-sediment formation cut slopes [20].

Prediction	SMS	SPRS	SIMS	SMART	LHRA
(1) Number of slopes assessed	47	47	47	47	47
(2) Number of recent landslides or failed slopes	29	29	29	29	29
(3) Number of slopes classified as High and Very High Hazard that actually failed	13	17	5	26	0
(4) Percentage of (3) compared with (2)	45%	59%	17%	90%	0%

Out of the rock mass classification systems, the SMR method has proven to be widely accepted for local practitioners working on rock slopes. As an example, recent case study on slope stability analysis of limestone cliff at Gunung Kandu, Gopeng by [21] highlight how the usage of SMR is significant for its quantification of rock slope stability in a practical method for large area of rock slope assessment. RMR and SMR have been noted as being useful for preliminary assessment of slope stability, incorporating geological, geometric, and engineering parameters to arrive at a quantitative value of rock mass quality [22].

Only few works have been found to modify the rock mass system in the context of local conditions. The most notable example is the Modified Slope Mass Rating (M-SMR) by [23–25] based on the works on the Crocker Formation in Kota Kinabalu. The system modifies RMR of [14] and SMR of [16] to consider the effect of alternating lithologies in heterogeneous rock formation, introducing the concept of 'lithological unit thickness' in lieu of assigning a single value for strength of intact rock material (UCS) for the whole rock unit (figure 1). The system is divided into six classes: very good (M-SMR 100–81), good (80–61), moderate (60–41), poor (40–21), very poor (20–1) and extremely poor (<1). Slope stabilization and protection measures are proposed for each classes (figure 2).

Another notable modification is the development of systematic cut slope stability evaluation by [26–27]. Here, the RMR and SMR values were compared with dip angle of the discontinuity (βi) and the peak friction angle, αp of discontinuity surfaces from laboratory tests for slope stability. The evaluation is based on the derived polynomial equations by [28] that correlates the αp of discontinuity planes from schist bedrocks with Joint Roughness Coefficient (JRC), which in effect include the parameter of discontinuity surface roughness for cut slope stability evaluation. The systematic approach propose four classifications for potential for failure: very high failure potential, intermediate failure potential, low failure potential, and stable (figure 3).



Lithology	Thickness (m)	Thickness %	Strength (UCS) MPa	Strength by lithology (MPa)	Strength of the SFRM (Mpa)
MSs	k	15.00	100.00	15.00	107.85
FSs	l	40.00	165.00	66.00	
VfSs	m	15.00	105.00	15.75	
Sz	n	30.00	37.00	11.10	
	Total	100.00			Very strong

Figure 1. Lithological unit thickness model. The final intact rock strength of slope forming rock material (SFRM) is represented by the sum of strength of all lithological in any particular slope [23].

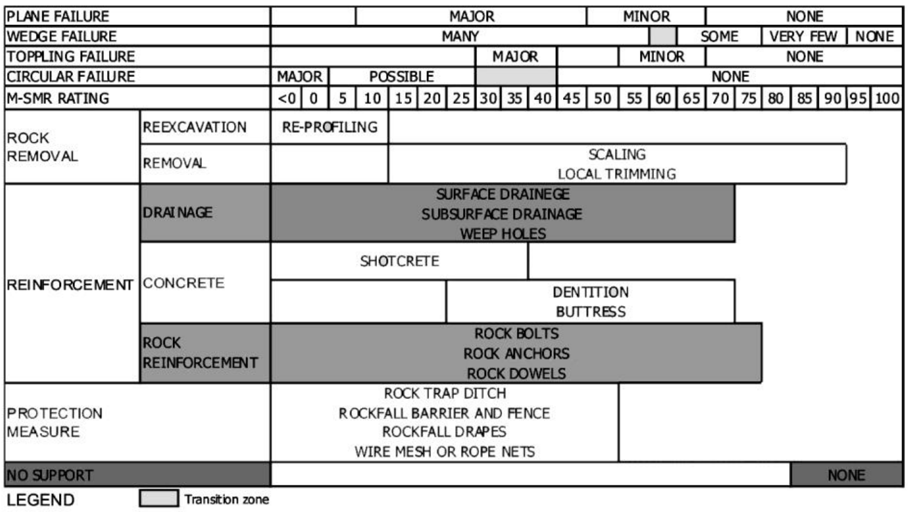


Figure 2. Slope stabilization and protection measures from M-SMR values [25].

Due to the tropical condition of Malaysia, weathering in rock mass is extremely common. Extensive studies on the weathering of bedrock in Malaysia have notably been carried out [29-31] with clear indication of the uppermost zone of weathering profile consisting of completely weathered bedrock material with unclear relict original bedrock texture. It is clear that any significant assessment of rock mass has to factor in the influence of weathering. [32] developed a typical mass weathering profile of tropically weathered granite (figure 4). The profile includes geological and structural parameters (joint characteristics, corestone occurrence, rock/soil ratio, mass homogeneity, colour of rock, and discoloration at joint' surfaces). The classification provides useful parameters for the preliminary stage of any civil engineering design, which potentially will save cost and time during site investigations for development of engineering work design parameters.

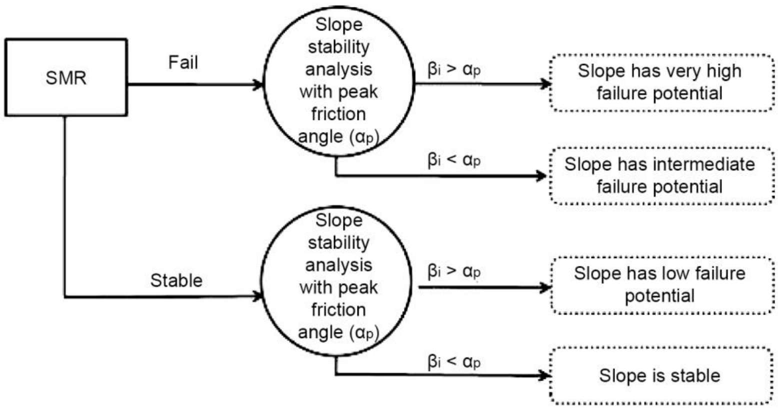


Figure 3. Diagram for systematic cut slope stability evaluation [26].

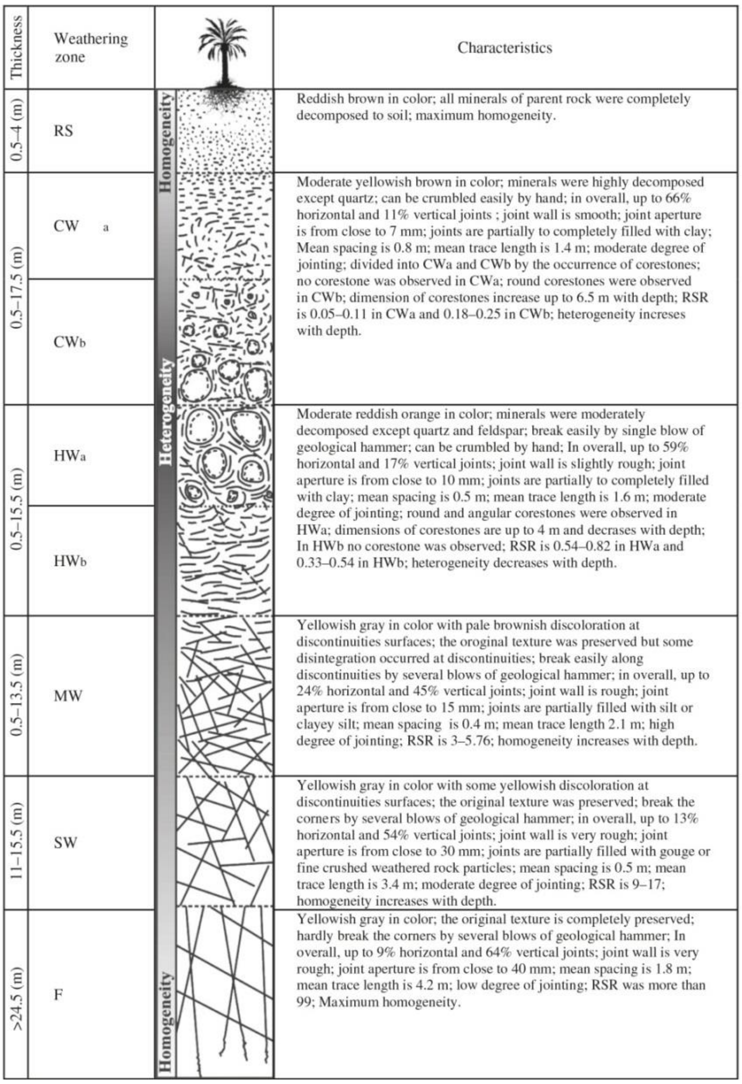


Figure 4. Typical mass weathering profile of tropically weathered granite [32].

3.2. Evaluation of rock mass classification

From the literatures mentioned in previous sections, it has been shown that rock mass classifications have been subjected to wide usage over a long period of time – leading to the identification of some inherent weakness and deficiency of the classification systems in reflecting the actual condition of rock mass. Some of the more inherent issue include discussions on the validity of rock quality designation (RQD) as parameters in rock mass classifications [33-35] or the correction factors applied to SMR (2) [12]. Perhaps more pressing in the context of Malaysia is that in most rock classification systems, the role of water movement has not been given significant proportion in the parameters [10]. This is especially significant for local climate, with water movement being the largest contribution factors for landslide, making up to 58% of landslide cases [2]. [10] suggests quantifying the hazard for failure in rock slopes (figure 5), where the use of factors related to precipitation and temperature characteristic of a study area allow adaptation of rock mass classification system to local climatic conditions.

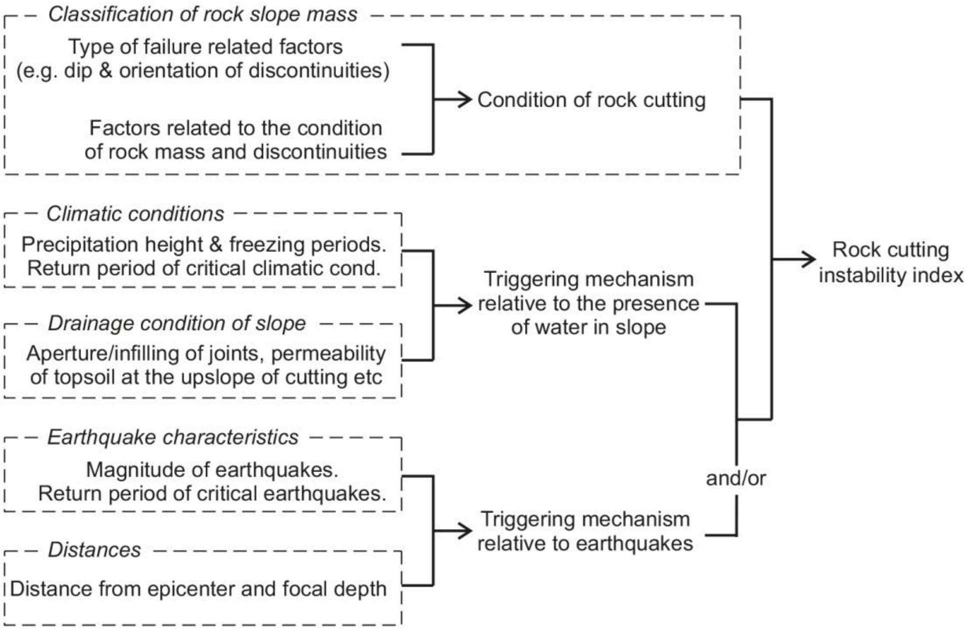


Figure 5. Proposed flow chart for quantification of the hazard for failure of rock cuttings [10].

[36] in their review of SMR have acknowledged some of the reported common issues found in the system, which includes: 1) rather conservative value of the classification in general; 2) extreme values of correction factor F3 proposed by Bieniawski is difficult to cope with in actual stability analysis of slope; 3) the failure modes derived from SMR occurs in reality; 4) excavation method is highly influential for slope's stability, and is necessary to include in the system; 5) practical difficulties for classification of slopes with berms; and 6) system does not consider the effect of slope height. It has also been noted that the rock mass classification systems are not applicable to complex cases involving variable slope geometric, coupled problems, and/or complex conditions of discontinuities [8]. The system however remains widely used, as it has been proven to be a powerful system in the initial stage of slope stability analysis, and continues to act as a common language for both engineering geologist and geotechnical engineers. Development of remote sensing technology, in particular the Light Detection and Ranging (LiDAR), have been incorporated into slope stability assessment and post-failure slope investigation. In their review of the development of SMR, [36] have pointed the usage of LiDAR that allows the generation of precise 3D point clouds from slopes which can be utilized to obtain parameters that are relevant for SMR or other rock mass classification. Usage of LiDAR for characterizing the parameters of rock slope (i.e. discontinuities) in local context have seen limited usage, with recent notable case involving the stability assessment of limestone rock cave [37]. The usage of LiDAR has been noted for its possibility of characterizing complex landslides along the transportation route in mountainous region [38], and offer the possibility of usage alongside conventional field data gathering due to the ability to cover large surface area in relatively short time.

4. Conclusion

Both kinematic analysis and rock mass classification have been established as valid and reliable methods for assessment of rock slope stability over the years, and have continued to be widely used in Malaysia, being widely accepted by both fields of engineering geology and geotechnical engineering. Although some flaws and limitations to the classification system have been discussed over the years, the simple nature of the system makes it desirable for practitioners to modify the parameters to better fit the context of local rock mass conditions. Any subsequent modifications to the system in the context of local conditions should consider the role of weathering and water movement in rock mass, as they have not been given much emphasis in current scope of available systems. The usage of laser scanning in slope stability assessment is an unexplored potential, and appears to be the next step forward in rock mass classification for slope.

5. References

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